Thermal Cycling and High Temperature Reverse Bias testing of Control and Irradiated Gallium Nitride Power Transistors

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Scope of Work

- A NEPP collaborative effort among NASA Centers to address reliability of new COTS wide bandgap power devices

Approach

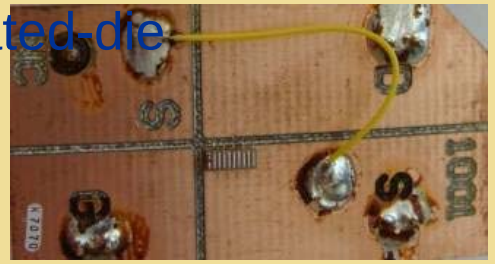
- Identify, acquire, and evaluate performance of emerging GaN (Gallium Nitride) & SiC (Silicon Carbide) power devices under the exposure to radiation, thermal cycling, and power cycling
- Document results and disseminate findings

Presentation

- Thermal cycling of 2nd generation GaN power FETs
- High temperature reverse bias (HTRB) testing of EPC2014 GaN FETs

Second Generation GaN FETs

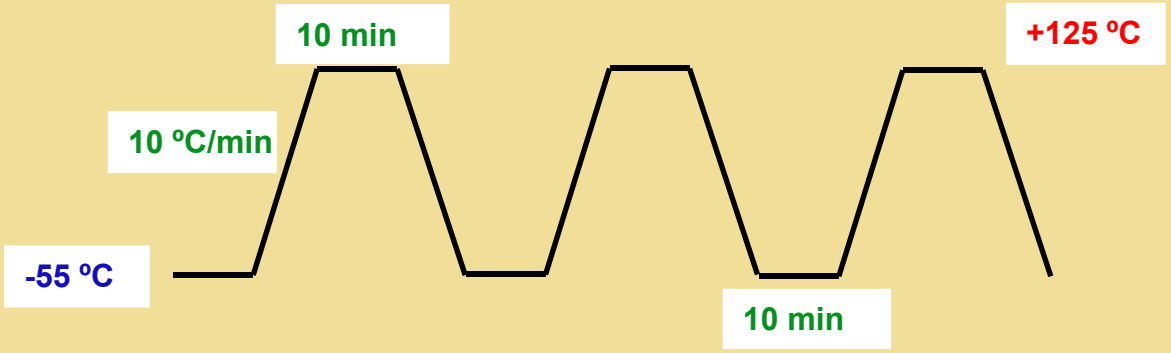
- EPC GaN transistors grown on Si wafer, passivated-die
- form with solder bumps; http://www.epc-co.com
- Irradiated by JPL at TAMU with 25 MeV/amu Xe (LET=40 MeV.cm2/mg)



EPC2015 (40V, 33A, 4mΩ)		EPC2014 (40V, 10A, 16mΩ)		EPC2012 (200V, 3A, 100mΩ)	
Control	**Irradiated**	**Control**	**Irradiated**	**Control**	**Irradiated**
K7301	K7303	K6985	K7325	A4754	K7348
K7302	K7305	K6986	K7328	A4755	K7353
K7304		K7333	K7347	A4756	K7354
K7306		K7336		A4757	K7359
K7311		K7346		A4758	K7370
K7312		K7072		A4759	K7395
					K7396
					K7399
					K7364

Thermal Cycling

- Cycling Profile:
  - Total # of Cycles 1000
  - Temperature rate of change: 10 ºC/min
  - Temperature range: -55 ºC to +125 ºC
  - Soak time at extreme temperatures: 10 min
- Repeat measurements on devices during cycling
- Perform measurements after conclusion of cycling activity



Thermal Cycling Test Setup

Parameters Investigated:

- I-V Output Characteristics
- Gate Threshold Voltage, V_{TH}
- Drain-Source On-Resistance, $R_{DS(on)}$
- Pre, during, & post-cycling, measurements at selected temperatures

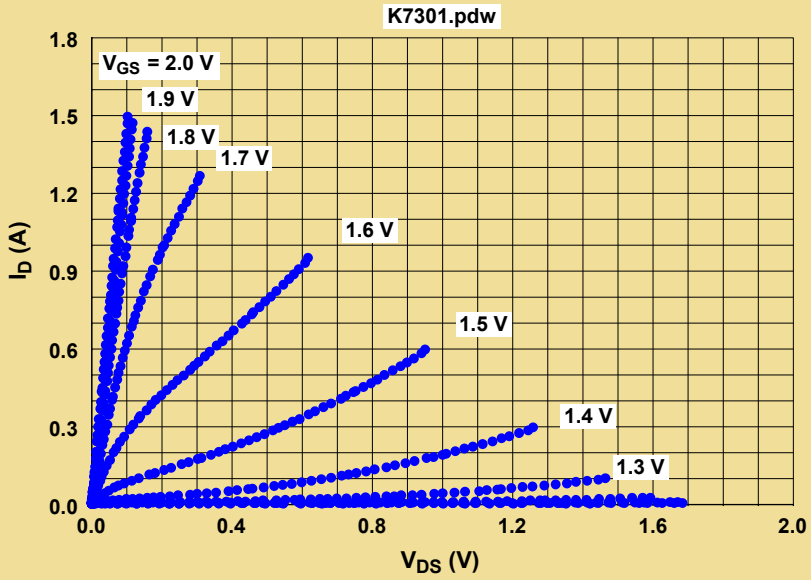
Equipment Used:

- SONY/Tektronix 370A Curve Tracer
- Keithley 238, 237, 2400 Source-Measure-Units
- LN-cooled Sun Systems Chamber

EPC2015 Enhancement Mode GaN Power FET

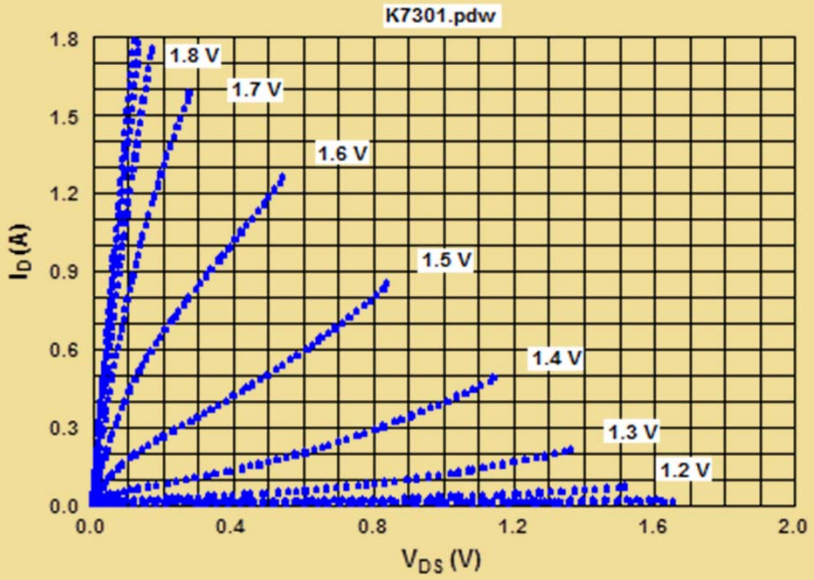
EPC2015 40V, 33A, 4mΩ	
Control Parts	**Irradiated Parts**
K7301	K7303
K7302	K7305
K7304	
K7306	
K7311	
K7312	

I-V Curves for K7301 (control)

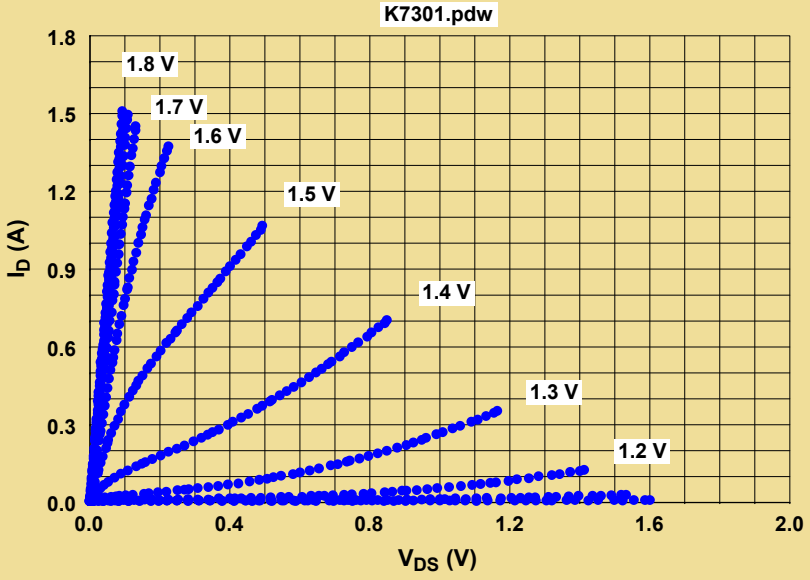


Pre-Cycling

EPC2015 GaN FET

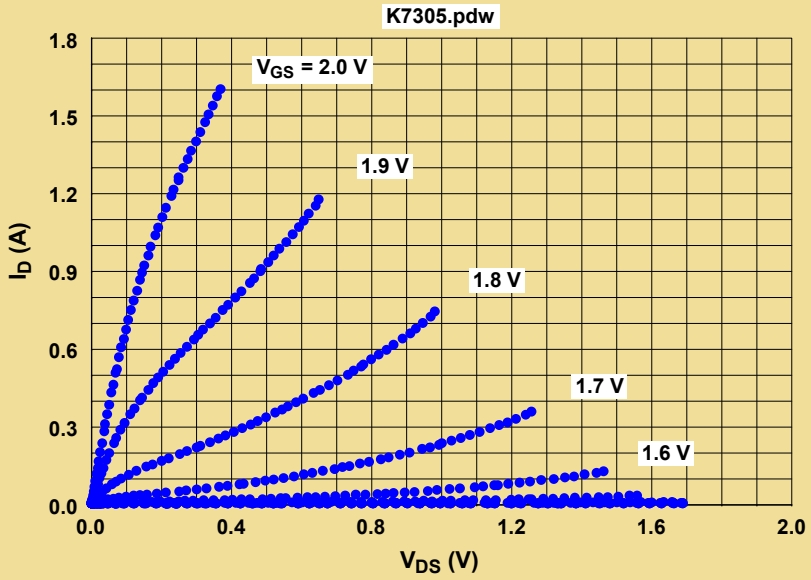


After 500 Cycles



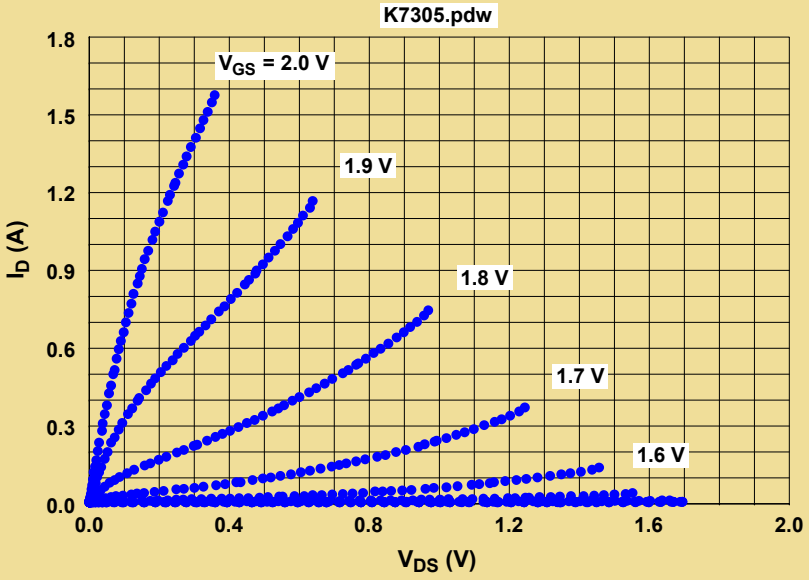
After 1000 Cycles

I-V Curves for K7305 (irradiated)

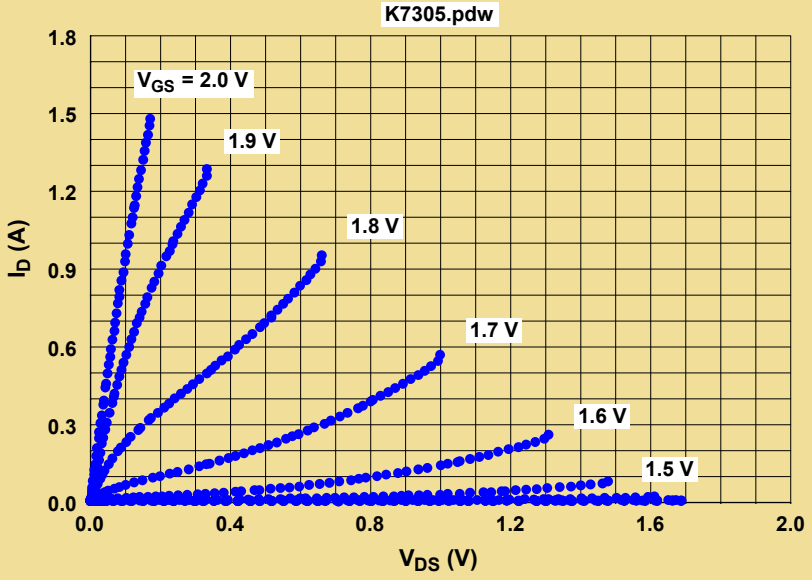


Pre-Cycling

EPC2015 GaN FET

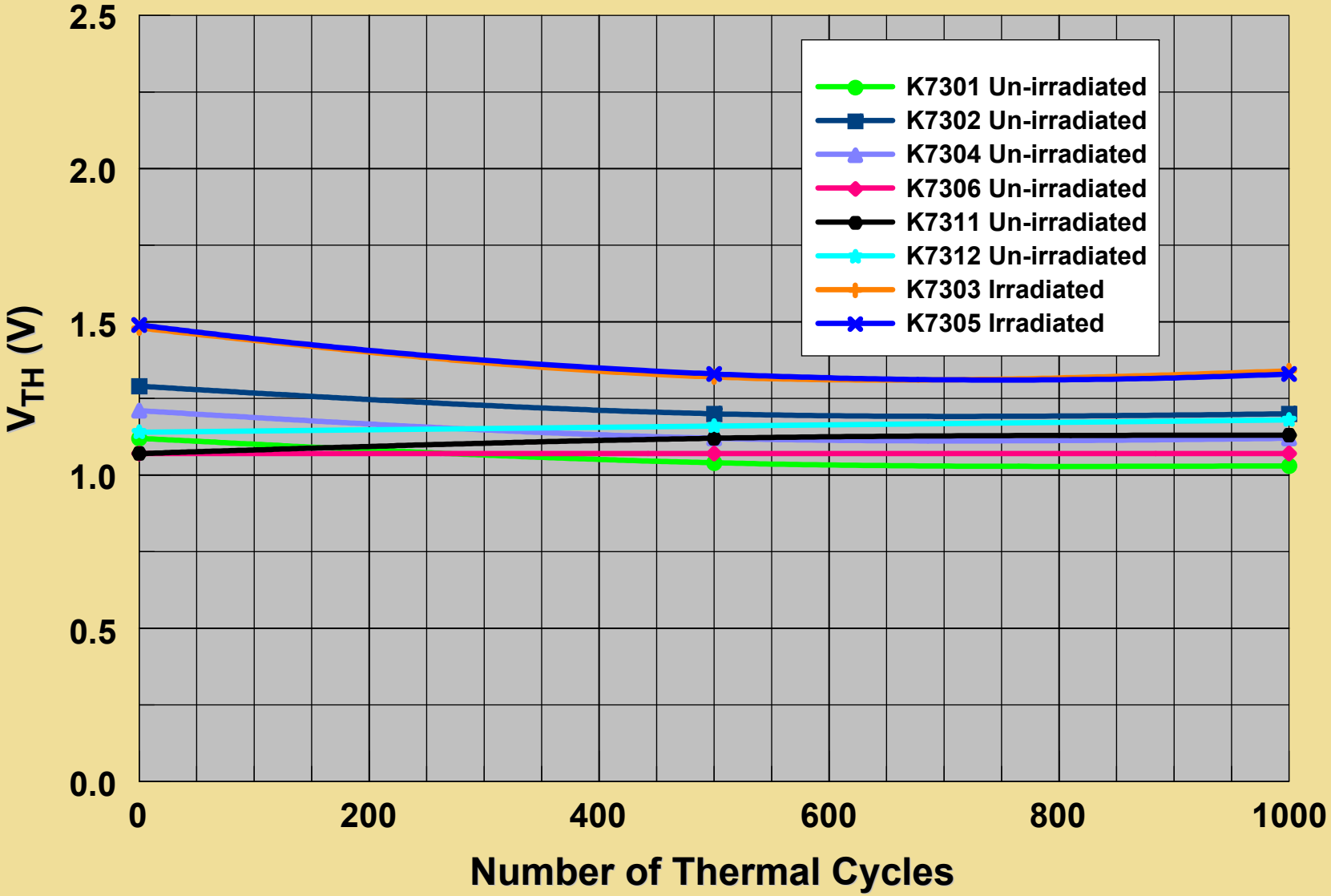


After 500 Cycles

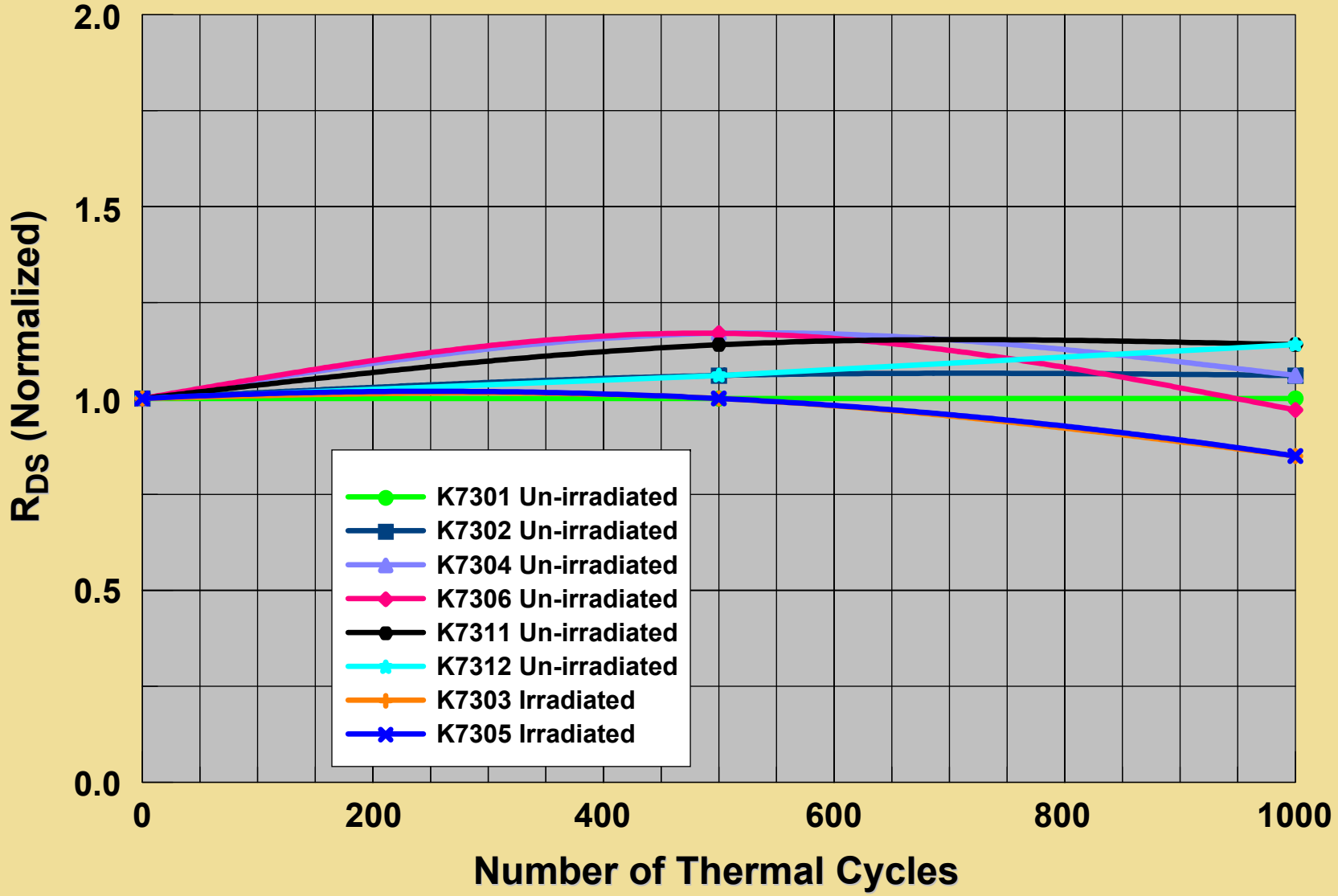


After 1000 Cycles

EPC2015 GaN FET
GATE THRESHOLD VOLTAGE, V_{TH}



EPC2015 GaN FET
Drain-Source On Resistance, $R_{DS(ON)}$



EPC2015 GaN FET

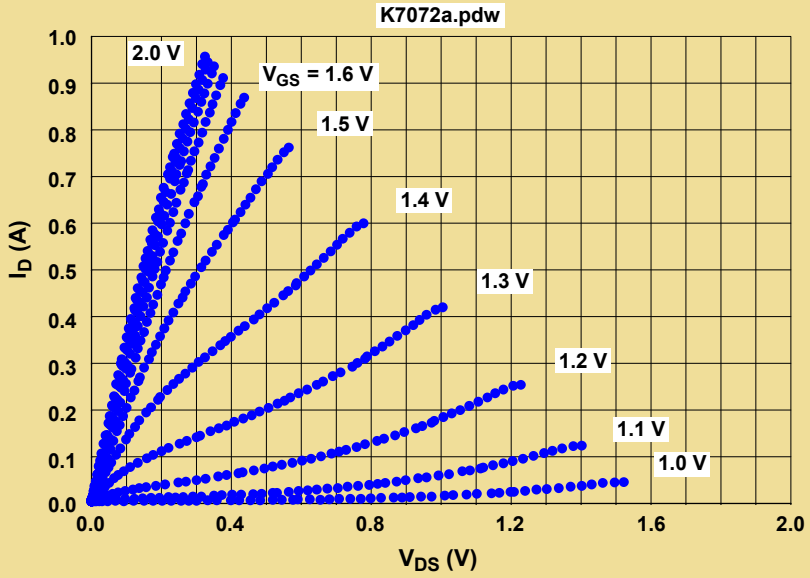
OBSERVATIONS

- All eight EPC2015 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 ^{0}C
- Radiation seemed to affect steepness of the I-V curves as reflected by the increase in V_{TH} & $R_{DS(ON)}$
- Insignificant changes in the I-V characteristics of control samples due to cycling
- Thermal cycling seemed to cause some recovery in the V_{TH} & $R_{DS(ON)}$ properties of the irradiated parts
- No alteration in device packaging or terminations

EPC2014 Enhancement Mode GaN Power FET

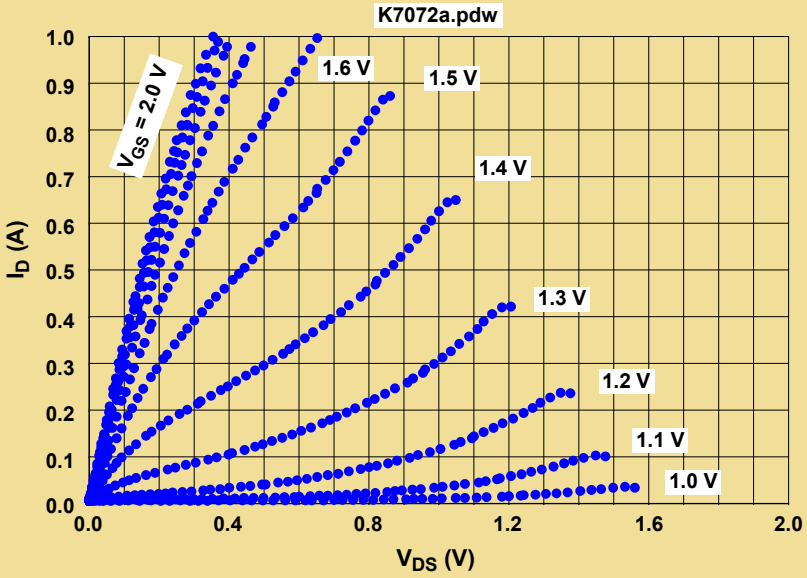
EPC2014 40V, 10A, 16mΩ	
Control Parts	**Irradiated Parts**
K6985	K7325
K6986	K7328
K7333	K7347
K7336	
K7346	
K7072	

I-V Curves for K7072 (control)

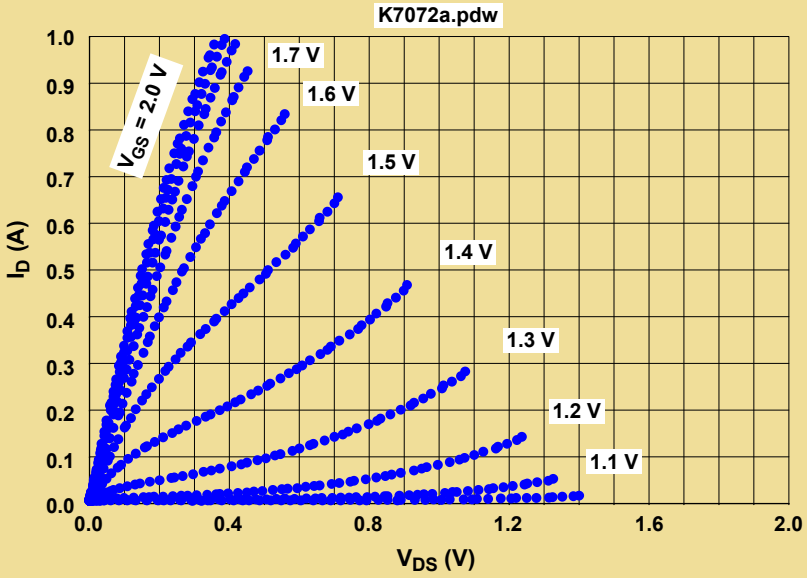


Pre-Cycling

EPC2014 GaN FET

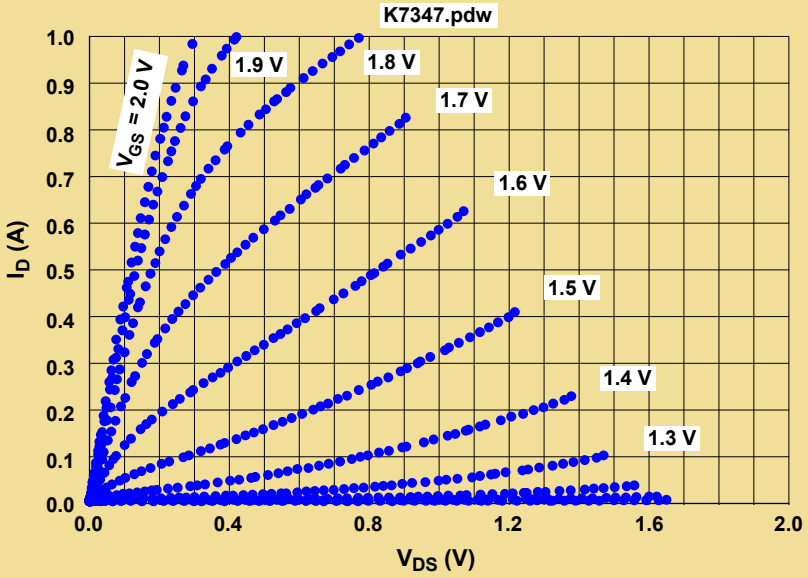


After 500 Cycles



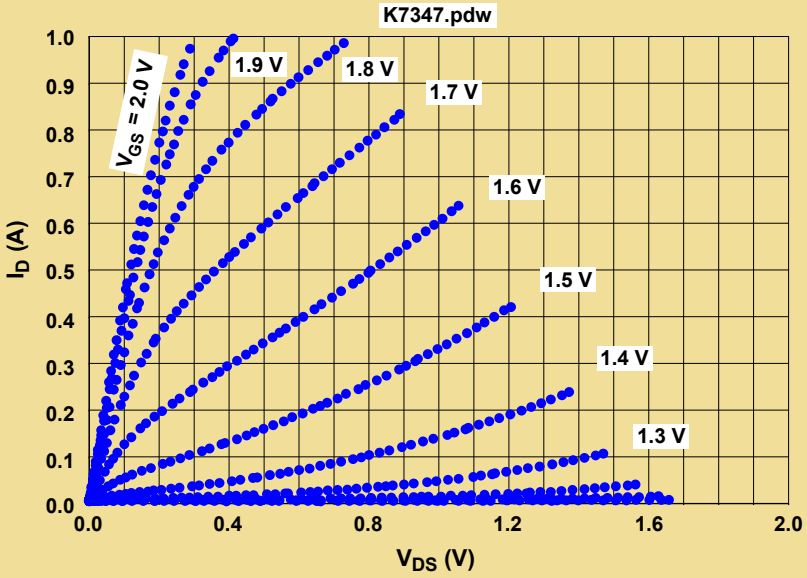
After 1000 Cycles

I-V Curves for K7347 (irradiated)

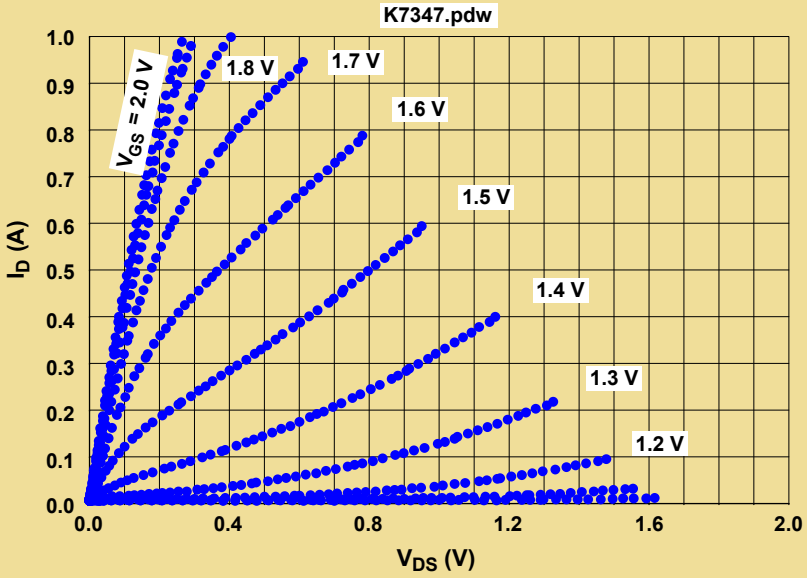


Pre-Cycling

EPC2014 GaN FET

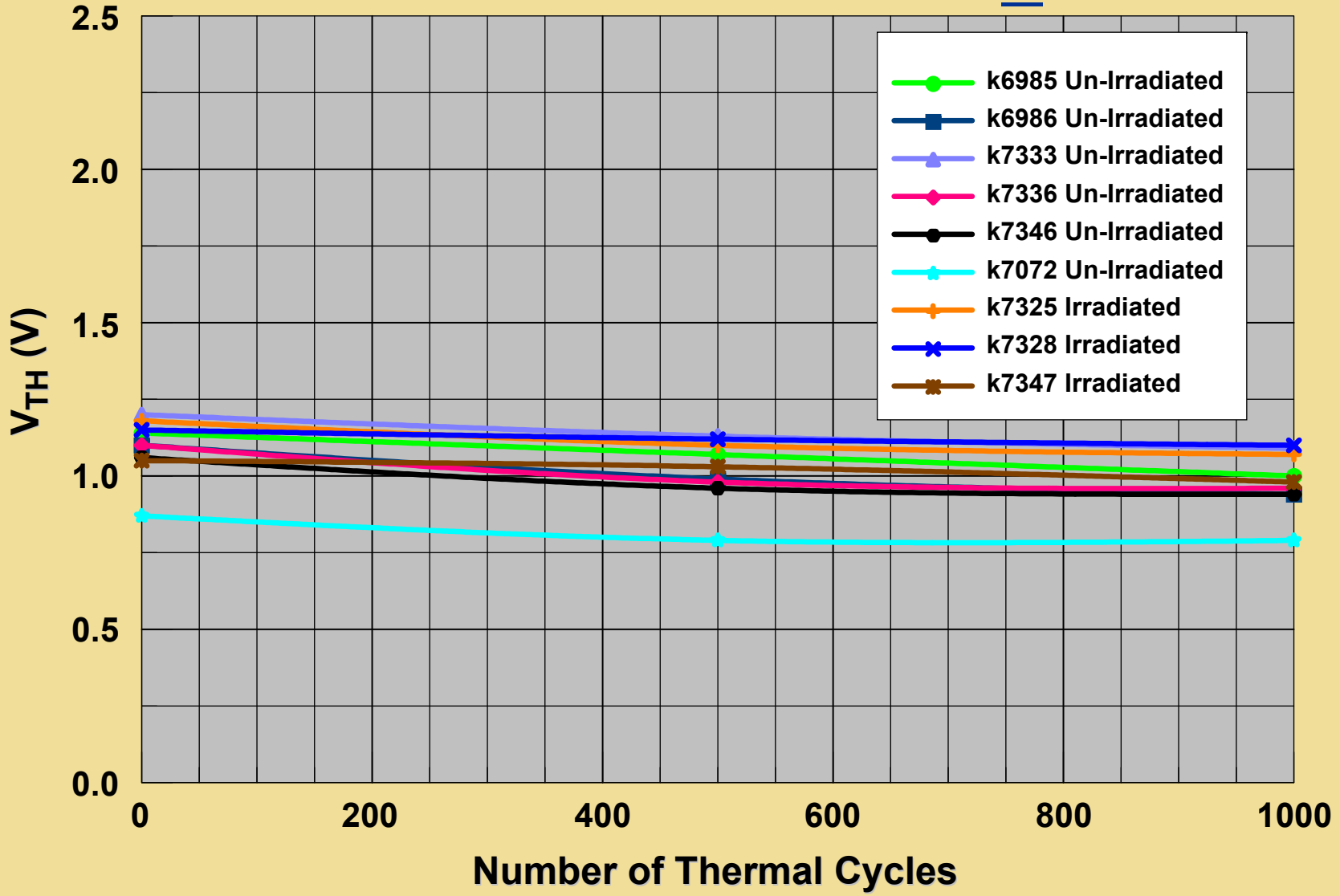


After 500 Cycles

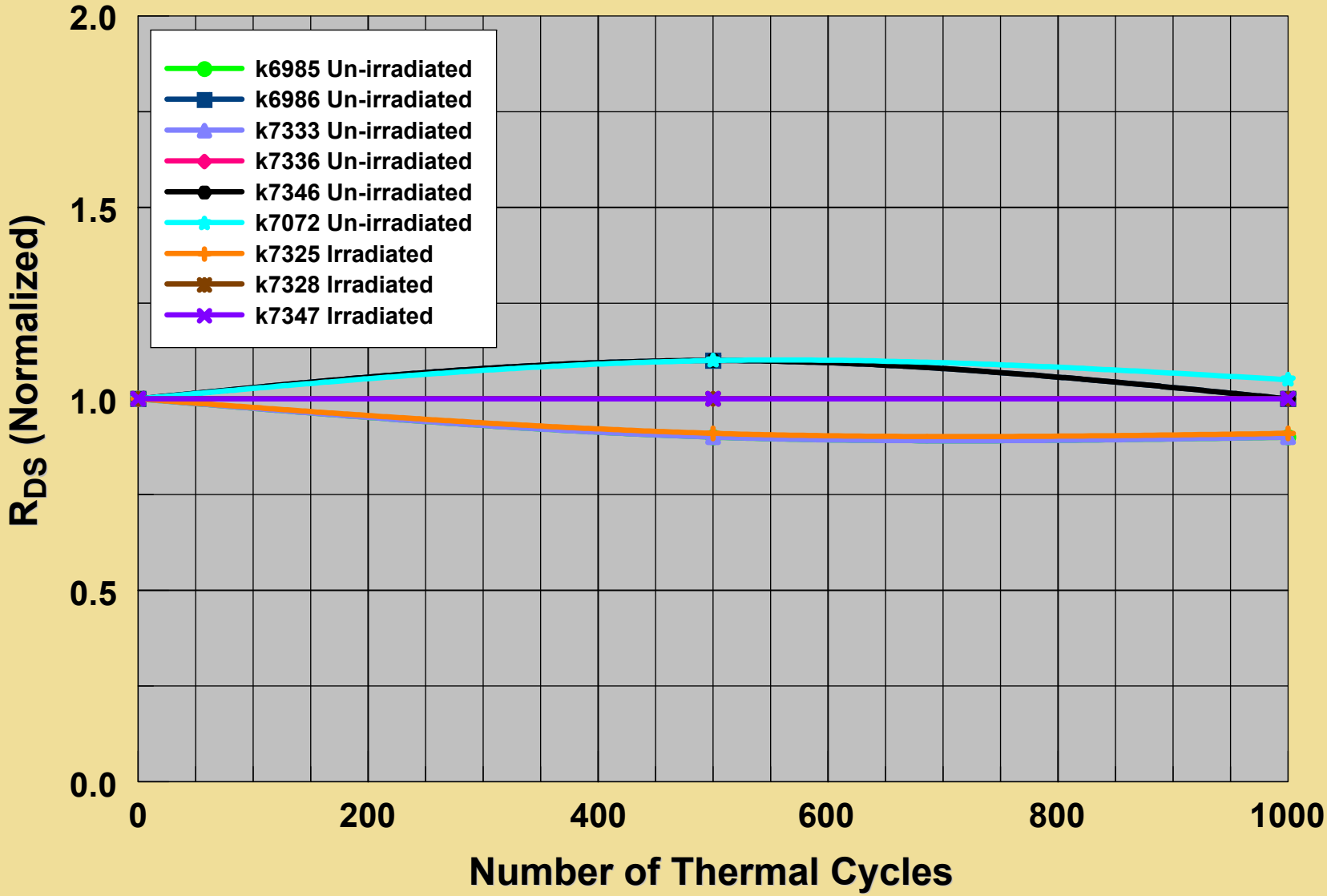


After 1000 Cycles

EPC2014 GaN POWER FET GATE THRESHOLD VOLTAGE, V_{TH}



EPC2014 GaN Power FET
Drain-Source On Resistance, $R_{DS(ON)}$



EPC2014 GaN POWER FET

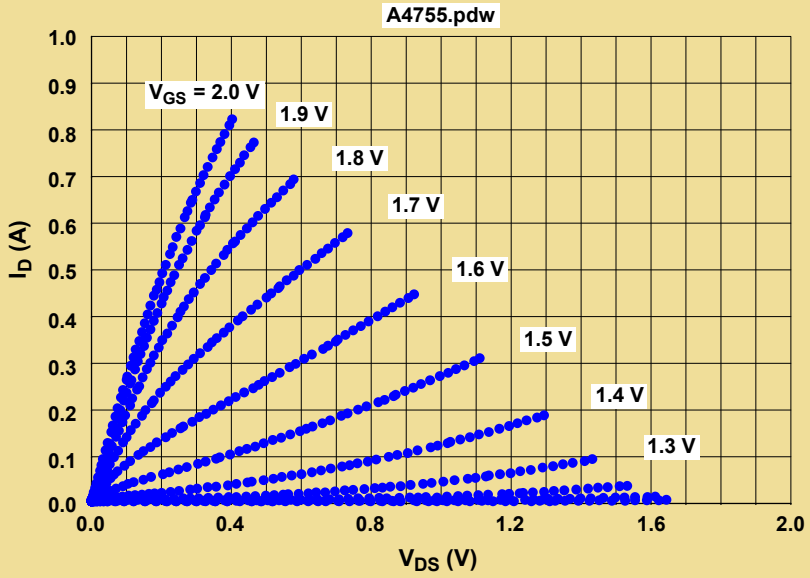
OBSERVATIONS

- All nine EPC2014 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 ^{0}C
- Slight changes in I-V curves of irradiated parts
- Thermal cycling seemed to slightly improve the I-V characteristics of both control and irradiated samples
- Part-to-part variation in output characteristics
- No alteration in device packaging or terminations

EPC2012 Enhancement Mode GaN Power FET

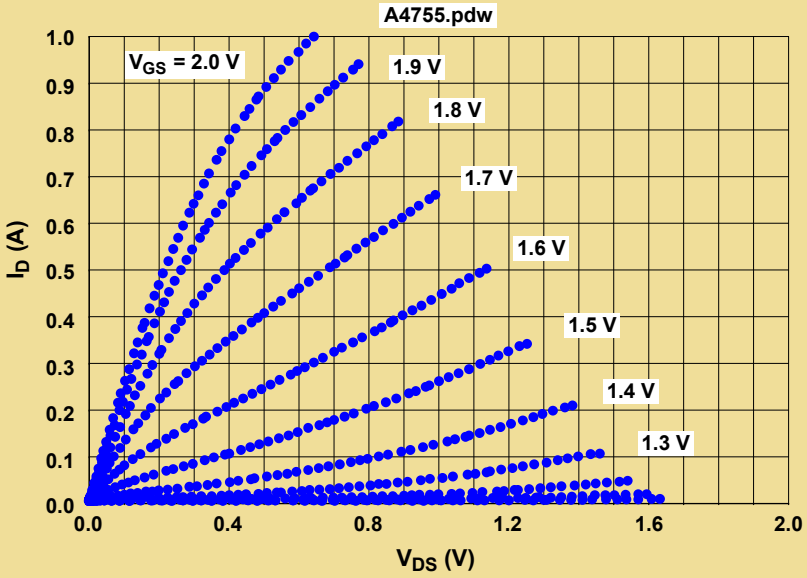
EPC2012 200V, 3A, 100mΩ	
Control Parts	**Irradiated Parts**
A4754	K7348
A4755	K7353
A4756	K7354
A4757	K7359
A4758	K7370
A4759	K7395
	K7396
	K7399
	K7364

I-V Curves for A4755 (control)

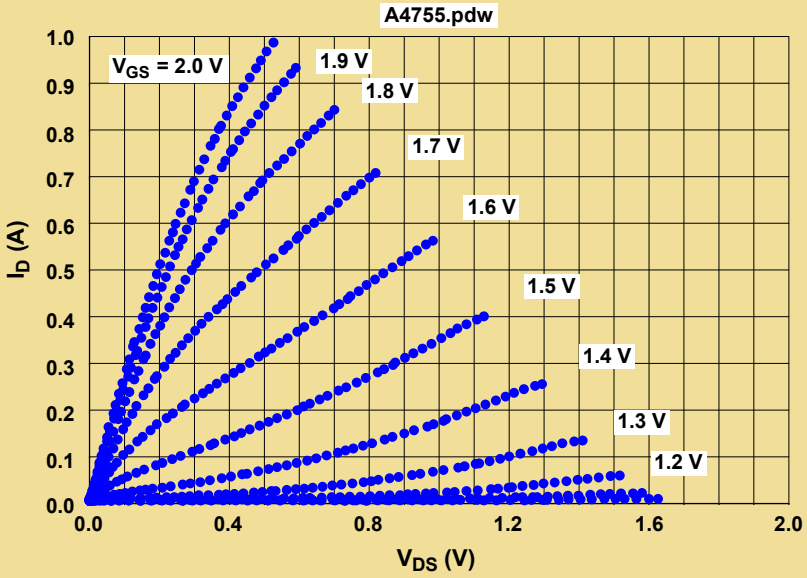


Pre-Cycling

EPC2012 GaN FET

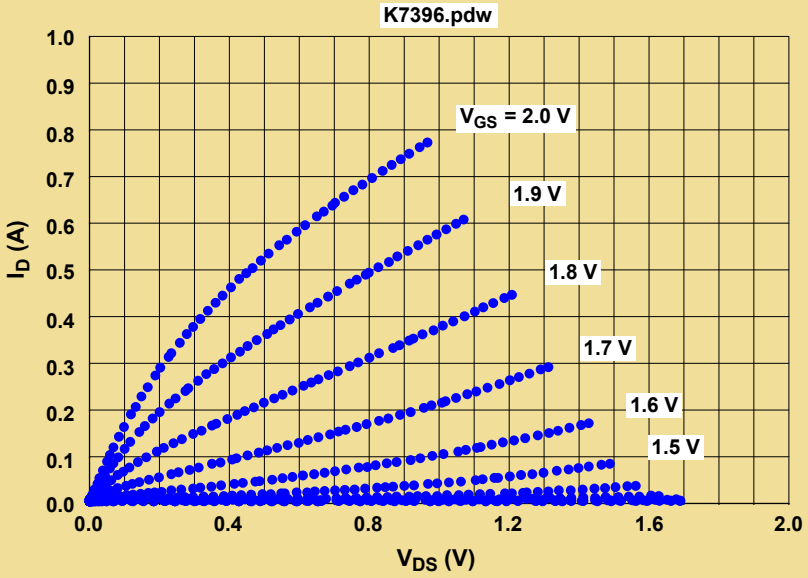


After 500 Cycles



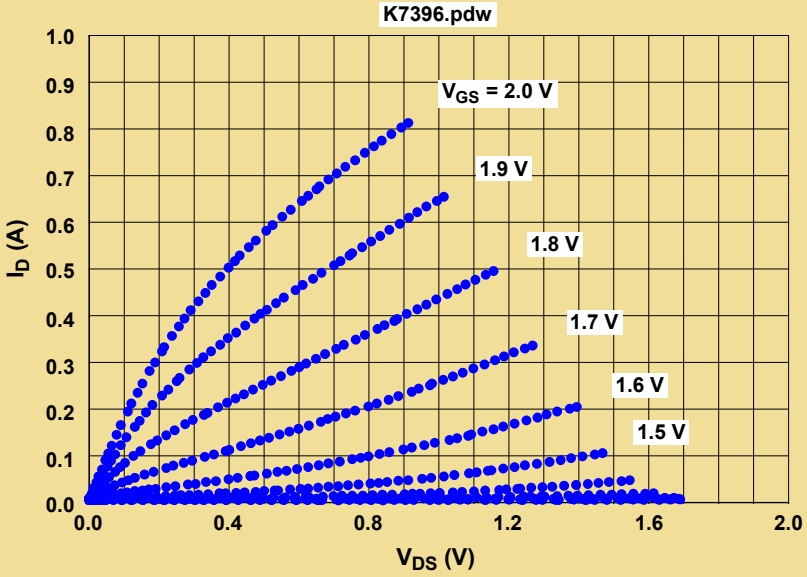
After 1000 Cycles

I-V Curves for K7396 (irradiated)

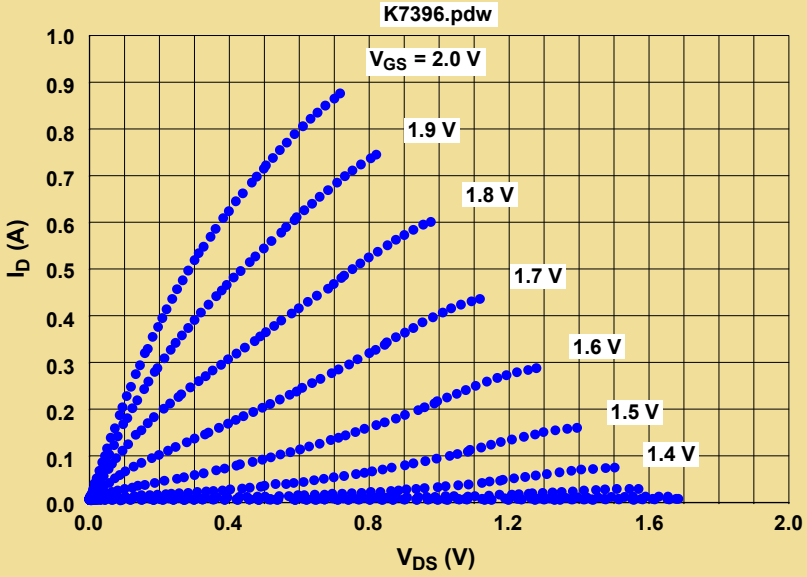


Pre-Cycling

EPC2012 GaN FET

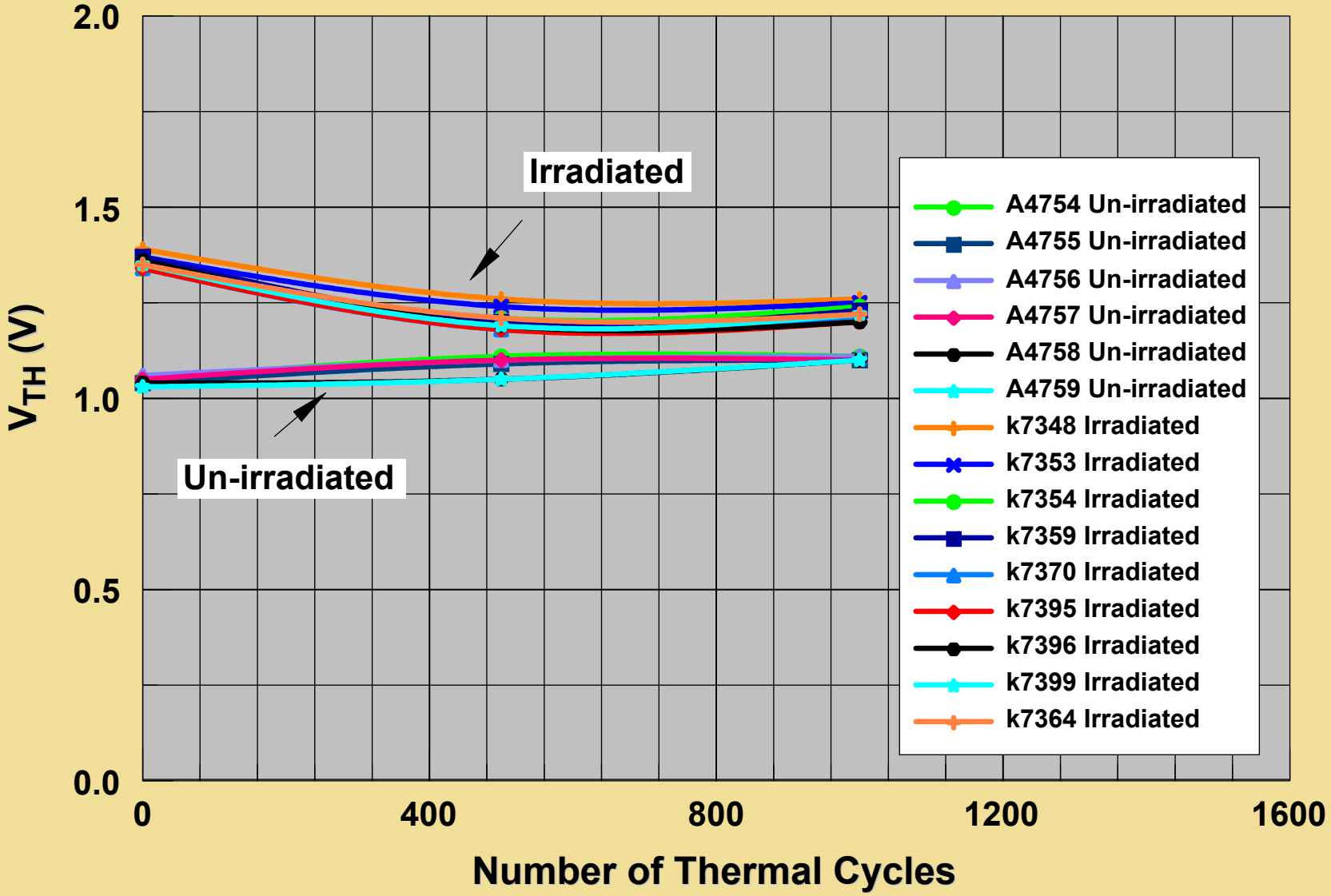


After 500 Cycles

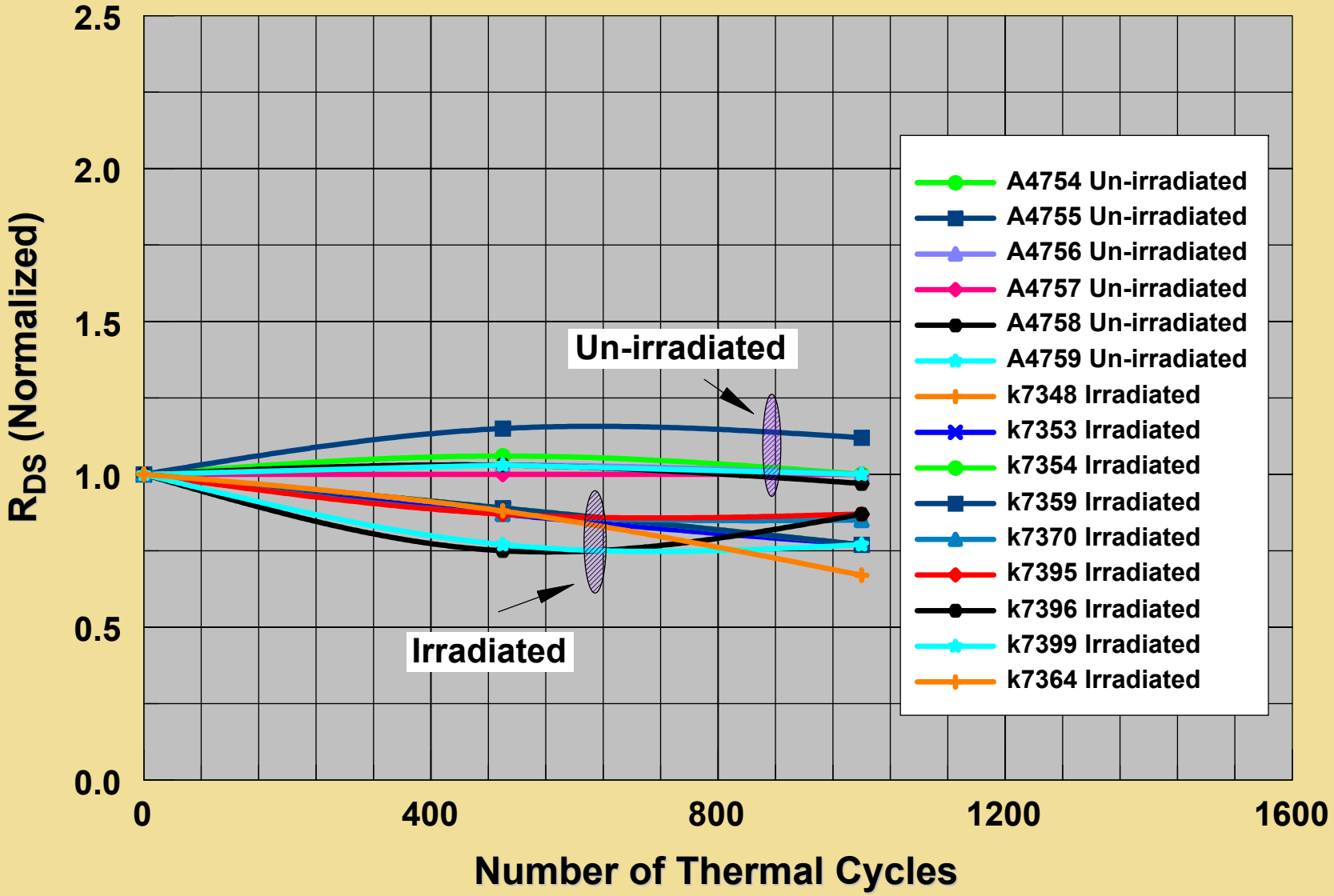


After 1000 Cycles

EPC2012 GaN POWER FET GATE THRESHOLD VOLTAGE, V_{TH}



EPC2012 GaN POWER FET
Drain-Source On Resistance, $R_{DS(ON)}$



EPC2012 GaN POWER FET

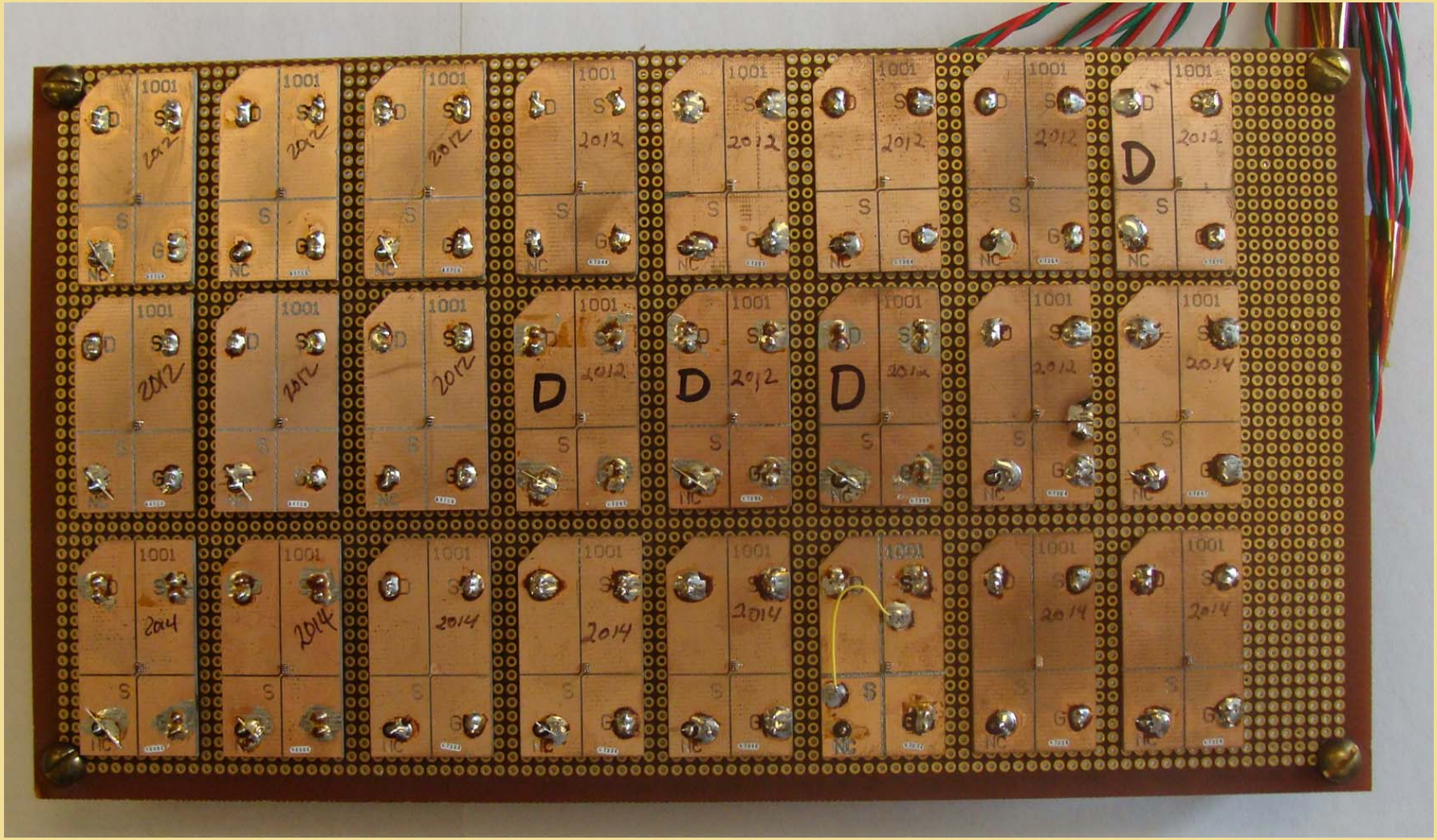
OBSERVATIONS

- All fifteen EPC2012 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 ^{0}C
- Radiation seemed to affect steepness of the I-V curves as reflected by the increase in V_{TH} & $R_{DS(ON)}$
- Thermal cycling seemed to influence characteristics of control as well as irradiated samples:
  - While V_{TH} of control parts increased slightly with cycling, those of the irradiated parts exhibited a decrease
  - No effect on $R_{DS(ON)}$ of majority of control parts but a decrease in this property was observed for the irradiated counterparts
- Part-to-part variability apparent in output characteristics
- No alteration in device packaging or terminations

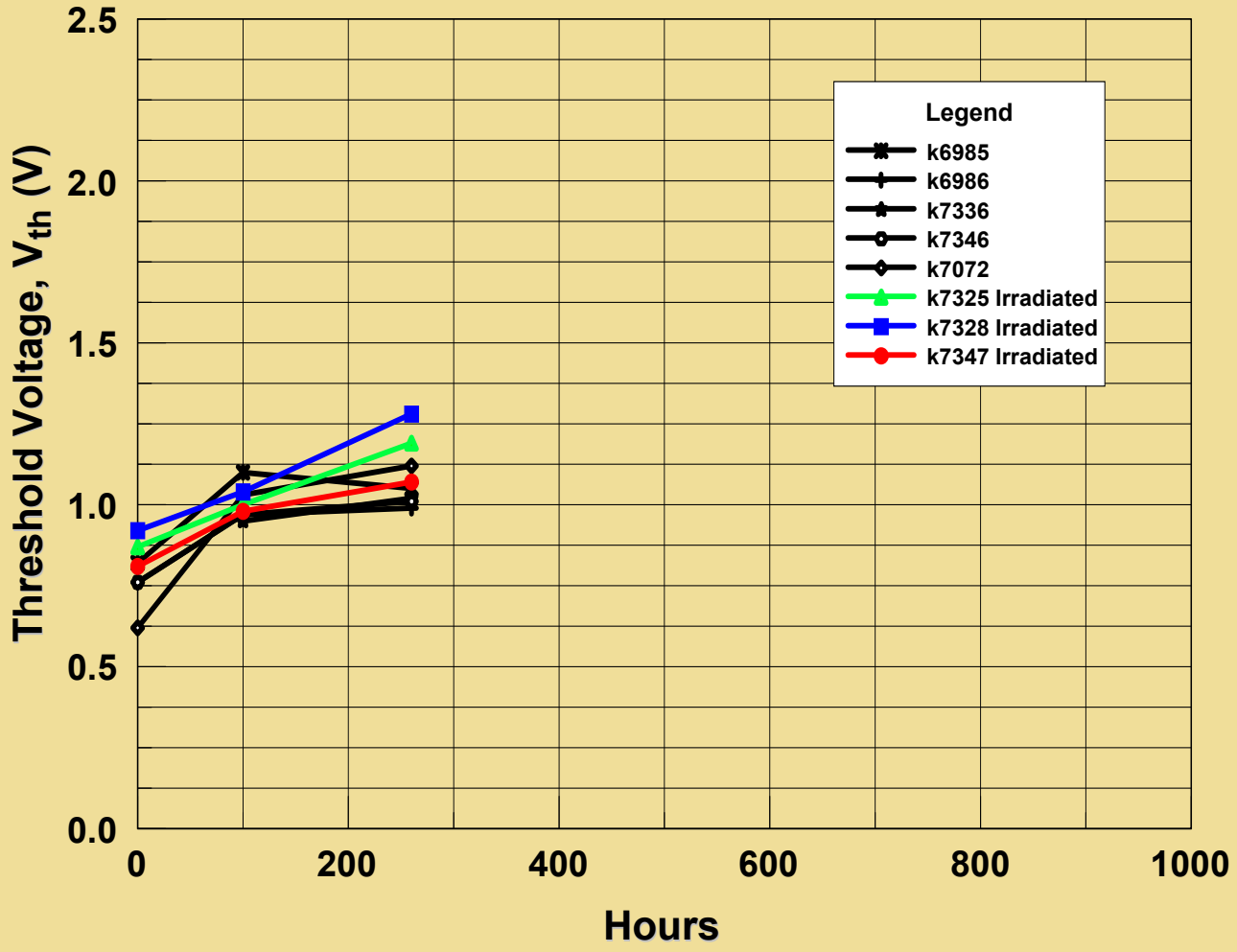
HIGH TEMPERATURE REVERSE BIAS (HTRB) TEST (Ongoing)

- EPC2014 GaN Power FET
- All devices had been given 1000 thermal cycles
- High Temperature Test Duration: 1000 hours
- Temperature: 125 °C
- Bias during heating: 80 % rated BV_{DSS}, V_{GS} = 0 V
- Parameters:
  - Gate threshold voltage
  - Drain leakage current
  - Gate forward leakage current
  - Gate reverse leakage current
  - I-V characteristic curves
- Measurements performed at room temperature at time intervals

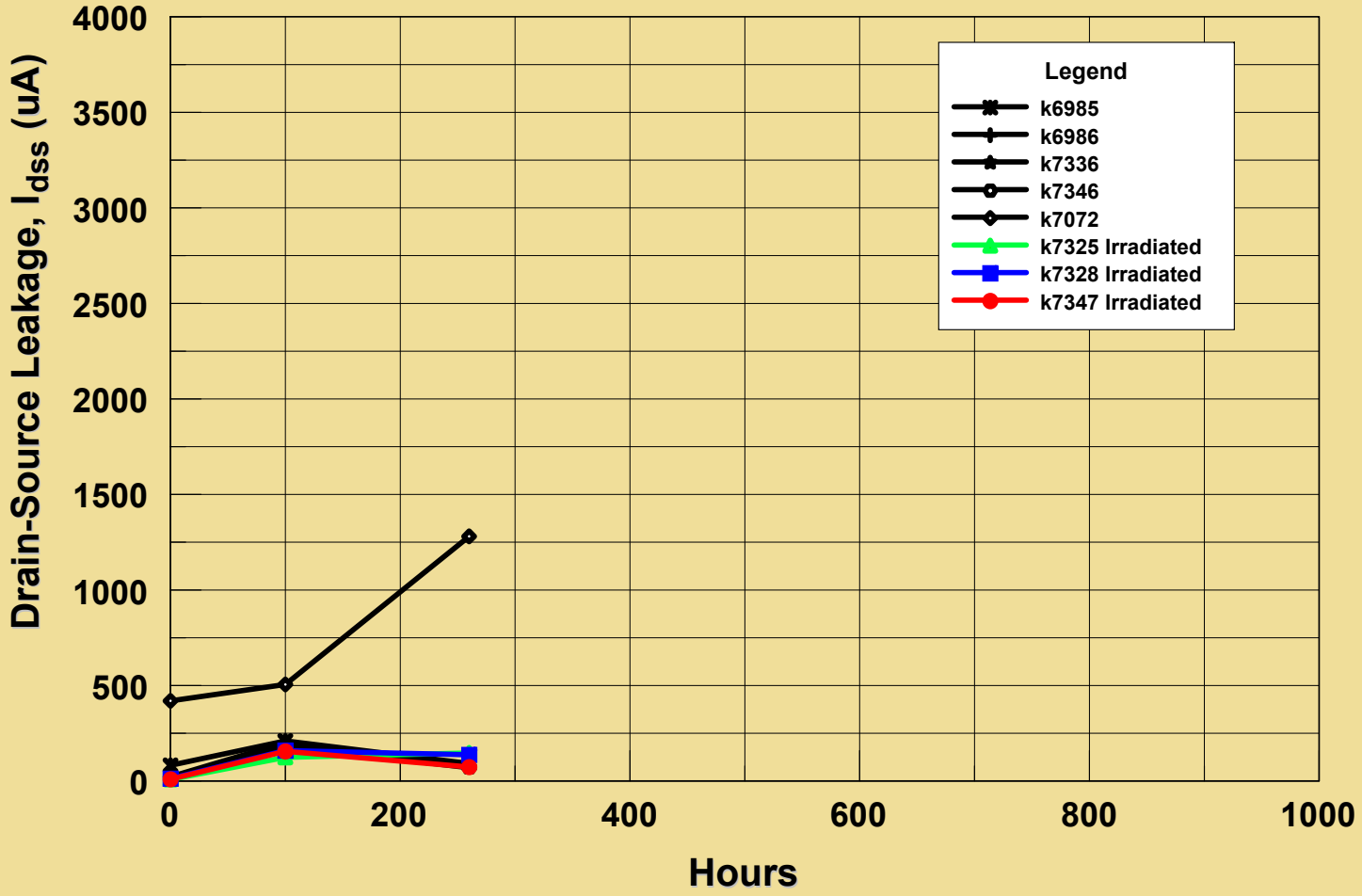
High Temperature Reverse Bias Test Board



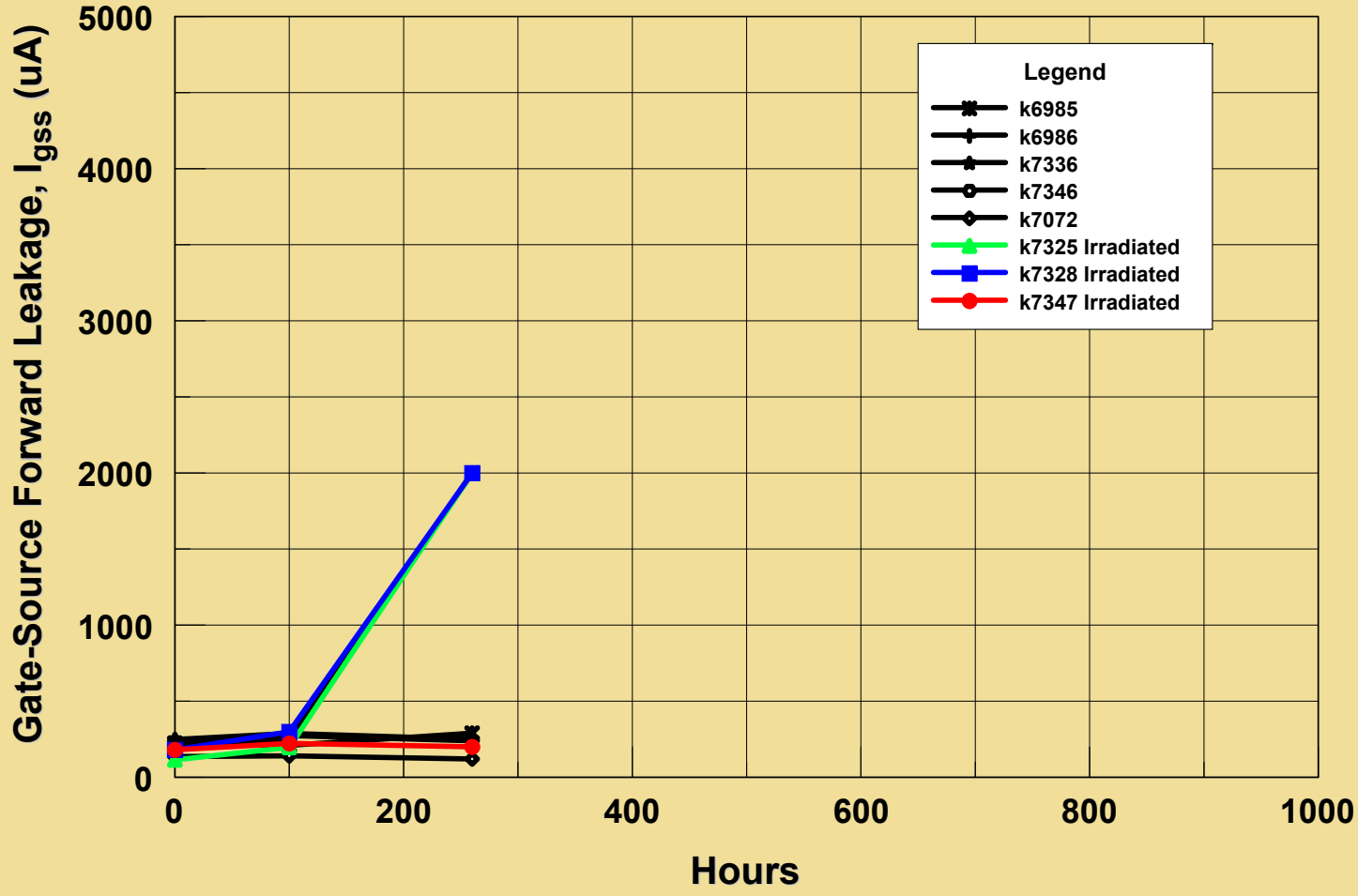
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE THRESHOLD VOLTAGE



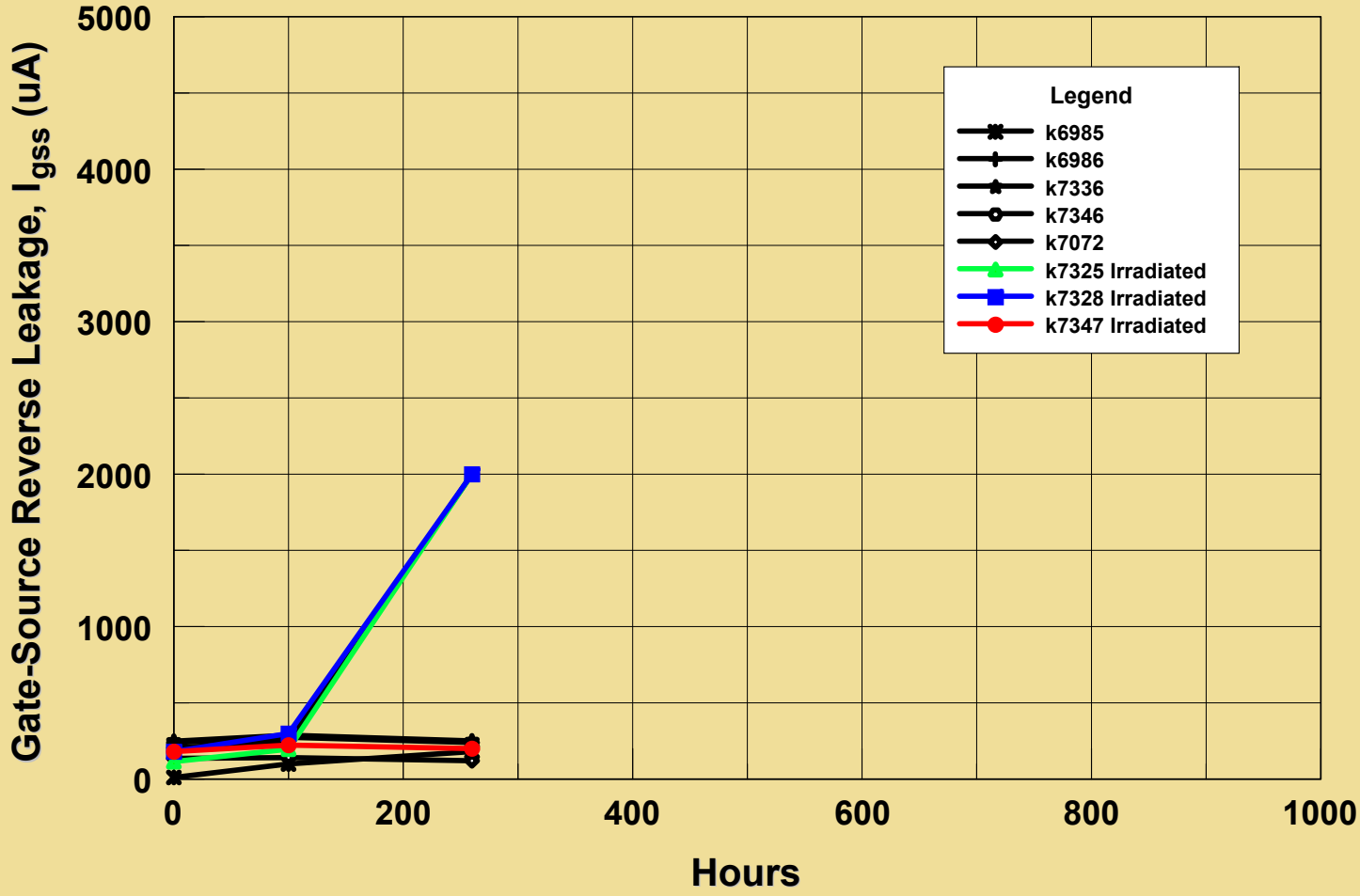
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
DRAIN-SOURCE LEAKAGE



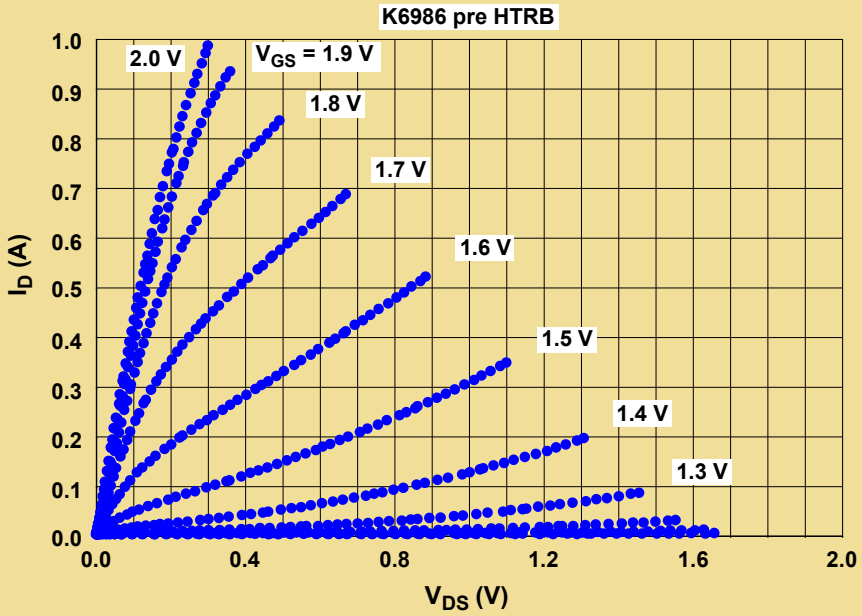
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE-SOURCE FORWARD LEAKAGE



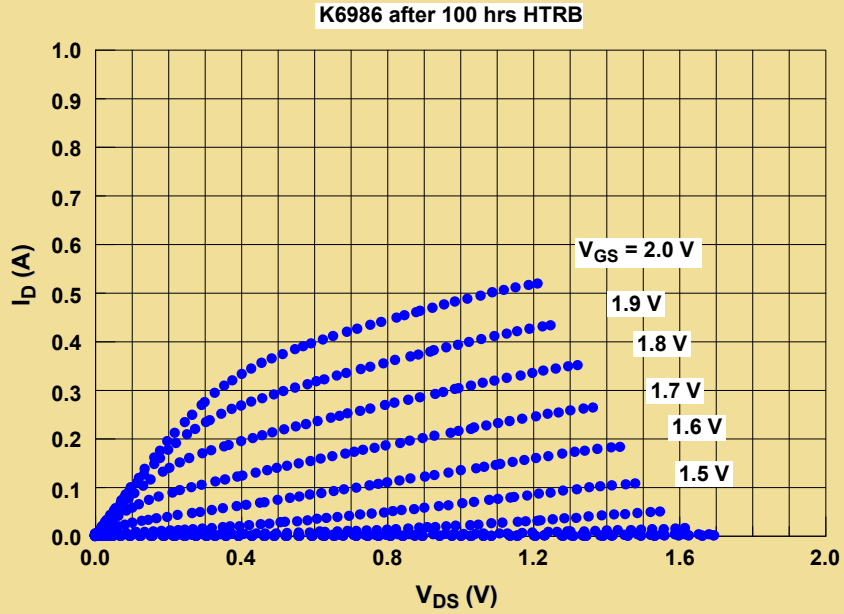
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE-SOURCE REVERSE LEAKAGE

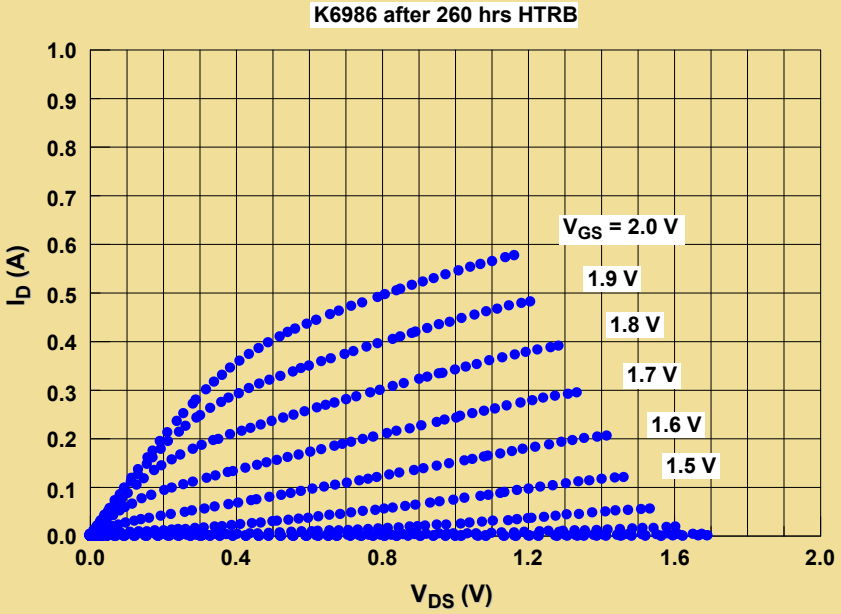


I-V Curves for K6986 (Control)

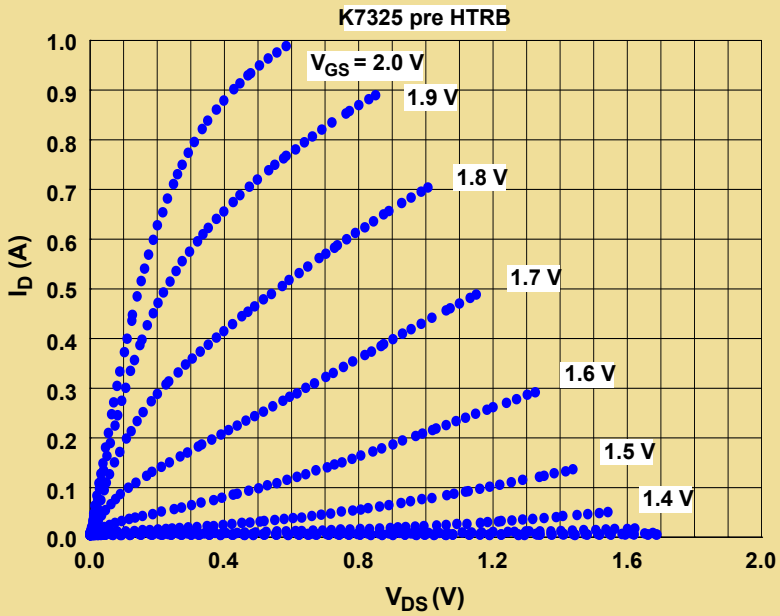


EPC2014 GaN FET
HIGH TEMPERATURE
REVERSE BIAS TEST

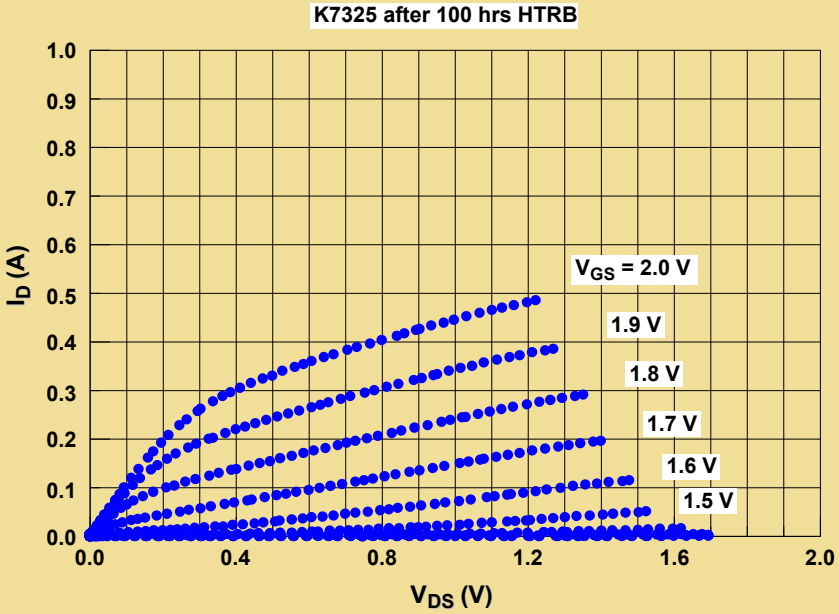


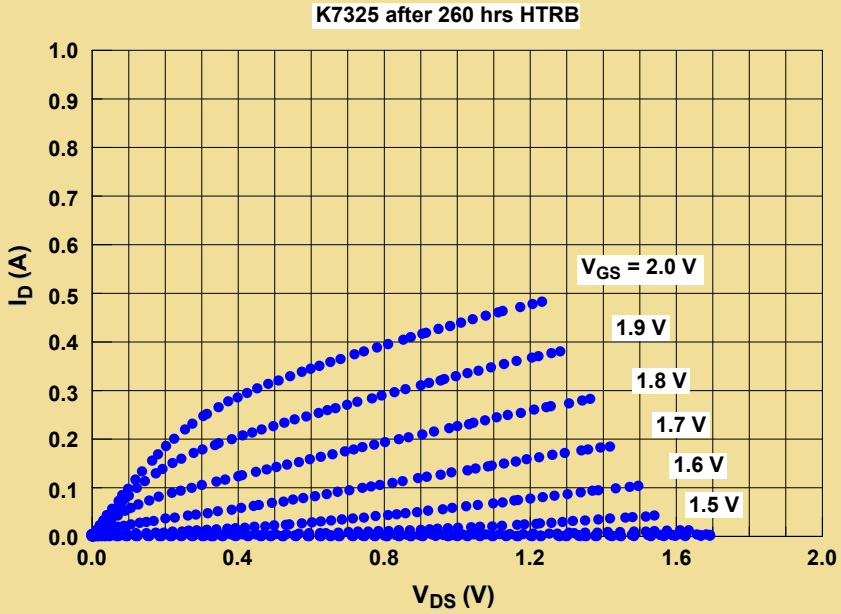


I-V Curves for K7325 (Irradiated)

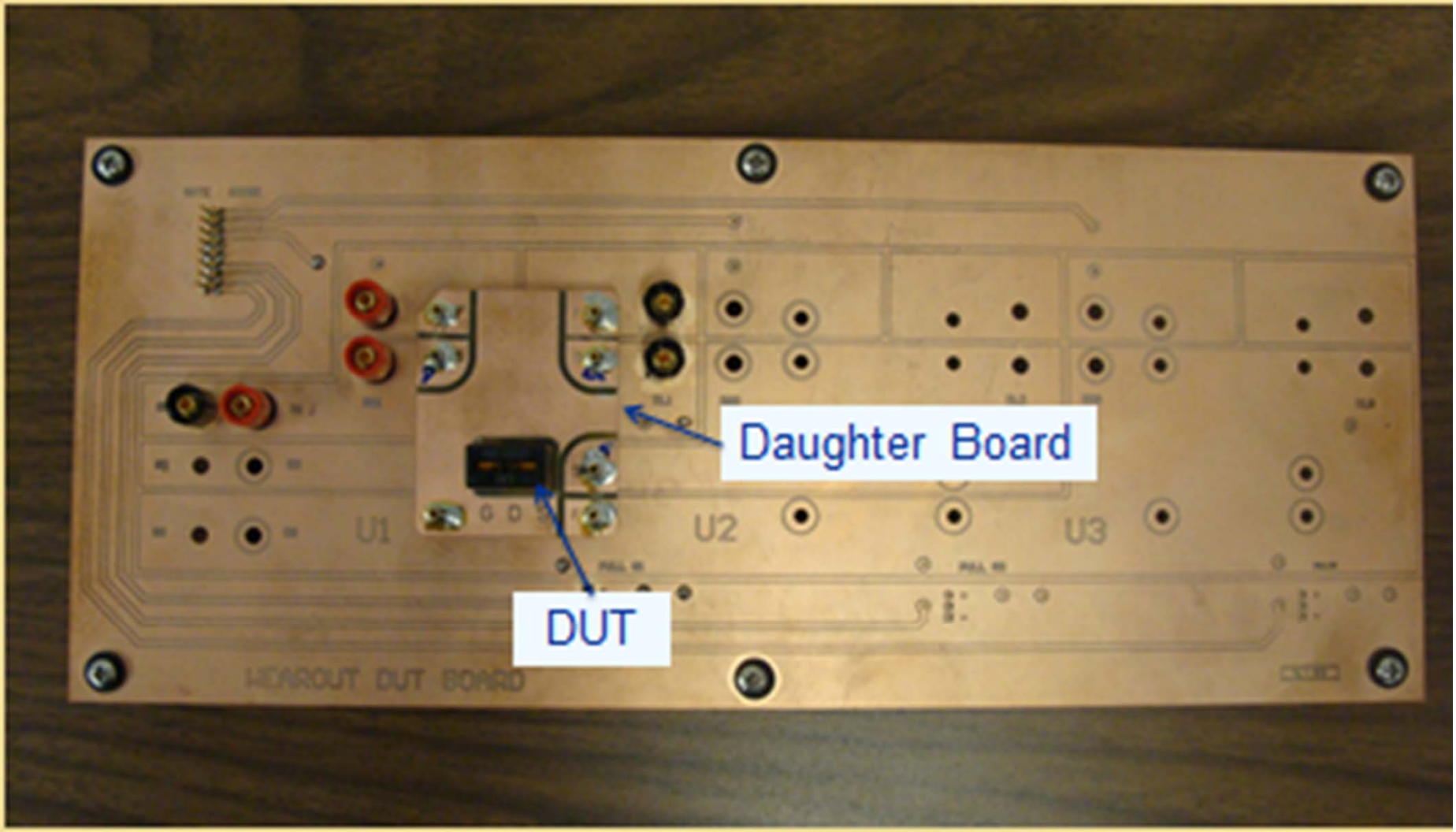


EPC2014 GaN FET
HIGH TEMPERATURE
REVERSE BIAS TEST





Prototype Transistor Test Board for Thermal Cycling and Other Tests



Planned Work

- Continue multi-stress tests on control and irradiated GaN & SiC power devices
- High Temperature Gate Bias (HTGB) Test
  - Bias: 80 % rated V_{GS}, V_{DS} = 0 V
- Power Cycling
  - Static (Gate DC voltage)
  - Dynamic (Gate AC voltage)

ACKNOWLEDGMENT

This collaborative work was performed in support of the NASA Electronic Parts and Packaging Program. Guidance and funding provided by the Program's co-managers Michael Sampson and Kenneth LaBel are greatly appreciated. Part of this work was done at the NASA Glenn Research Center under GESS-3 Contract # NNC12BA01B.